4. SOURCE REDUCTION AND RECYCLING

This chapter presents estimates of GHG emission reductions and carbon sequestration resulting from source reduction and recycling of eight materials: newspaper, office paper, corrugated boxes, aluminum cans, steel cans, and three types of plastic (LDPE, HDPE, and PET).

To estimate GHG emissions associated with source reduction and recycling (and other MSW management options), we used a baseline scenario in which the material is not manufactured (as shown in Exhibit 1-2). Based on this measurement convention, we estimated that source reduction results in no GHG emissions for all materials. Moreover, source reduction of paper results forest carbon sequestration (as discussed in Chapter 3), which is treated as a GHG reduction. (In this analysis, source reduction is assumed to entail either material "lightweighting" or extension of a product's useful life. We assume no substitution by another material or product, and thus we assume no offsetting GHG emissions from another material or product. Thus the data should not be used directly for estimating GHG impacts of source reduction that involves material substitution.[46])

Manufacturing from recycled inputs generally requires less energy than manufacturing from virgin inputs. Thus, manufacturing from recycled inputs generally results in lower GHG emissions than manufacturing from virgin inputs. Our estimates of the GHG implications of recycling, which are developed in this chapter, show that recycling reduces GHG emissions for each of the eight materials studied.

4.1 GHG IMPLICATIONS OF SOURCE REDUCTION

When a material is source reduced (i.e., less of the material is made), the greenhouse gas emissions associated with making the material and managing the post-consumer waste are avoided. In addition, when paper products are source reduced, trees that would otherwise be harvested are left standing and continue to grow, so that carbon remains sequestered in forests (as described in Chapter 3). The additional carbon sequestered due to source reduction is counted in the same way as a reduction in GHG emissions.

As discussed above, under the measurement convention used in this analysis, source reduction has (1) zero manufacturing GHG emissions, (2) positive forest carbon sequestration benefits for paper products (as estimated in Chapter 3), and (3) zero waste management GHG emissions. Exhibit 4-1 presents the GHG implications of source reduction. The values for forest carbon sequestration were copied from Exhibit 3-8.

[46] The GHG impacts of source reduction involving material substitution could be estimated based on (1) the data provided in this report for the material that is source reduced, (2) the mass substitution rate for the material that is substituted, and (3) data in this report for the material substituted. If source reduction involves substitution of a product not analyzed in this report, one would also need to assume that the final fabrication energy per ton of substitute product is similar to the final fabrication energy per ton of product analyzed in this report.

Exhibit 4-1
Greenhouse Gas Emissions for Source Reduction
(MTCE/Ton of Material Source Reduced)

		Change in Forest Carbon Storage (Minus sign indicates incremental carbon storage)		Net GHGs		
Material	GHG Emissions from Raw Materials Acquisition and Manufacturing	Source Reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs	Waste Management GHGs	Source reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs
Newspaper	0.00	-0.48	-0.73	0.00	-0.48	-0.73
Office Paper	0.00	-0.53	-0.73	0.00	-0.53	-0.73
Corrugated Cardboard	0.00	-0.44	-0.73	0.00	-0.44	-0.73
Aluminum Cans	0.00	0.00	0.00	0.00	0.00	0.00
Steel Cans	0.00	0.00	0.00	0.00	0.00	0.00
HDPE	0.00	0.00	0.00	0.00	0.00	0.00
LDPE	0.00	0.00	0.00	0.00	0.00	0.00
PET	0.00	0.00	0.00	0.00	0.00	0.00

In order to compare source reduction to another solid waste management option, we added the GHG savings from source reduction to the GHG emissions avoided by not using another solid waste management option (e.g., landfilling). With this approach, we determined the overall difference in GHG emissions between (1) source reducing one ton of material and (2) manufacturing and then managing (post-consumer) one ton of the same material. Such comparisons are made in the executive summary chapter and in Chapter 8 of this report. Overall, source reduction has lower GHG emissions than the other waste management options.

4.2 GHG IMPLICATIONS OF RECYCLING

When a material is recycled, it is used in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. As with source reduction of paper products, recycling of paper products also results in forest carbon sequestration (as described in Chapter 3), which is counted in the same way as a reduction in GHG emissions.

Although most of the materials considered are modeled as being recycled in a "closed loop" (e.g., newspapers are recycled into new newspapers), two of the products considered · office paper and corrugated boxes · are modeled as being recycled in an "open loop" (i.e., they are recycled into more than one product). Office paper is modeled as being recycled into either office paper or tissue paper, in proportions of 45 percent and 55 percent, respectively. Corrugated boxes are modeled as being recycled into either corrugated boxes (70 percent) or folding boxes (30 percent). By developing GHG estimates for all four of these products we were able to estimate the GHG implications of "open loop" recycling of office paper and corrugated boxes.[47]

To compare recycling to another solid waste management option such as landfilling, we compared the total GHG emissions from manufacturing and then recycling, to the GHG emissions from manufacturing and then landfilling. Specifically, we subtracted (1) the GHG emissions from manufacturing, minus the avoided GHG emissions from remanufacture using recycled (rather than virgin) inputs, from (2) the GHG emissions from manufacturing and then landfilling.[48] Overall, recycling has lower GHG emissions than all other waste management options except for source reduction.

When any material is recovered for recycling, some portion of the recovered materials are unsuitable for use as recycled inputs (these materials are discarded either in the recovery stage or in the remanufacturing stage). Consequently, less than one ton of material is generally made from one ton of recovered inputs. These losses may be quantified as "loss rates." We obtained estimates of loss rates from Franklin Associates, Ltd. and the Tellus Institute. For each material, we then averaged the estimated rates from the two firms. The loss rates for each material are shown in Exhibit 4-2.

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[47] Note that this modeling approach does not fully reflect the prevalence and diversity of open loop recycling. For example, (1) office paper and corrugated cardboard are recycled into a variety of manufactured products, not just the two products we selected for each, and (2) additional materials are also recycled in an open loop.

[48] We assumed that recycling does not change demand for the products made from recycled materials. Thus, we assumed that each incremental ton of recycled inputs would displace an equivalent amount of virgin inputs. To estimate the avoided GHG emissions from remanufacture from recycled inputs, we compared the GHG emissions from manufacturing a material from 100 percent virgin inputs, to the GHG emissions from manufacturing the material from 100 percent recycled inputs.

Exhibit 4-2
Loss Rates For Recovered Materials

(a) Material	(b) Percent of Recovered Materials Retained in the Recovery Stage	(c) Tons of Product Made Per Ton of Recycled Inputs in the Manufacturing Stage	(d) Tons of Product Made Per Ton of Recovered Materials
Newspaper	90	0.85	0.77
Office Paper	88	0.75	0.66
Corrugated Cardboard	92	0.84	0.77
Aluminum Cans	95	0.87	0.83
Steel Cans	98	1.00	0.97
HDPE	87	1.00	0.87
LDPE	87	1.00	0.87
PET	87	1.00	0.87

Explanatory notes: The value in column "b" accounts for losses such as recovered newspapers that were unsuitable for recycling because they were too wet. Column "c" reflects process waste losses at the manufacturing plant or mill. Column "d" is the product of the values in columns "b" and "c."

Exhibit 4-3 shows the greenhouse gas implications of recycling each material. The estimates in this exhibit account for the loss rates for each material. Thus, the exhibit shows the GHG emissions, in metric tons of carbon equivalent (MTCE), per short ton of material recovered (rather than emissions per ton of material made with recycled inputs).

In addition, Exhibit 4-3 sums, for each material, the differences between manufacture from virgin and recycled inputs for (1) energy-related greenhouse gas emissions (both in manufacturing processes and transportation), (2) process non-energy-related greenhouse gas emissions, and (3) forest carbon sequestration.

4.3 LIMITATIONS

Because the data presented in this chapter were developed earlier in Chapters 2 and 3, the limitations discussed in those chapters also apply to the values presented here. Three other limitations are as follows:

- There may be GHG impacts from disposal of industrial wastes, particularly paper sludge at paper mills. Because of the complexity of analyzing these second-order effects, and the lack of data, we did not include them in our estimates. We did perform a screening analysis for paper sludge, however, based on (1) data on sludge generation rates and sludge composition (i.e., percentage of cellulose, hemicellulose, lignin, etc. in sludge), and (2) professional judgment on the methane generation rates for cellulose, etc. The screening analysis indicated that net GHG emissions (methane emissions minus carbon sequestration) from paper sludge are probably on the order of 0.00 MTCE per ton of paper made from virgin inputs to 0.01 MTCE per ton for recycled inputs. Our worst case bounding assumptions indicated maximum possible net GHG emissions ranging from 0.03 to 0.11 MTCE per ton of paper (depending on the type of paper and whether virgin or recycled inputs are used).

- There is uncertainty in the loss rates - some materials recovery facilities and manufacturing processes may recover or use recycled materials more or less efficiently than estimated here.

- We used a simple representation of recycling as mostly closed loop. We considered open loop processes for only two products, and even there our open loop model was simplified - we considered only two products that might be made from each original product.

Exhibit 4-3
Greenhouse Gas Emissions for Recycling
(MTCE/Ton of Material Recovered)

(a) Material	(b) Recycled Input Credit*: Process Energy GHG	(c) Recycled Input Credit*: Transportation Energy GHG	(d) Recycled Input Credit*: Process Non-Energy GHG	(e) Forest Carbon Sequestration	(f) GHG Reductions From Using Recycled Inputs Instead of Virgin Inputs
Newspaper	-0.14	0.01	0.00	-0.73	-0.86
Office Paper	-0.08	-0.01	0.00	-0.73	-0.82
Corrugated Cardboard	0.03	0.00	0.00	-0.73	-0.70
Aluminum Cans	-2.66	-0.07	-1.24	0.00	-3.97
Steel Cans	-0.57	-0.01	0.00	0.00	-0.57
HDPE	-0.31	-0.02	-0.06	0.00	-0.38
LDPE	-0.44	-0.01	-0.06	0.00	-0.51
PET	-0.58	-0.02	-0.03	0.00	-0.63

*Material that is recycled post-consumer is then substituted for virgin inputs in the production of new products. This credit represents the difference in emissions that results from using recycled inputs rather than virgin inputs. It accounts for loss rates in collection, processing, and remanufacturing. Recycling credit is based on weighted average of closed and open loop recycling for office paper and corrugated cardboard. However, all other estimates are only for the products themselves.

Explanatory notes: Columns "b" and "c" show the reduction in process energy GHGs and transportation energy GHGs from making each material from recycled inputs, rather than virgin inputs. The values in columns "b" and "c" are based on (1) the difference in energy-related GHG emissions between making one ton of the material from 100% virgin inputs and from 100% recycled inputs, multiplied by (2) the estimated tons of material manufactured from one ton of material recovered, after accounting for loss rates in the recovery and remanufacturing stages. We first estimated the values in columns "b" and "c" based on data provided by Franklin Associates, Ltd. (FAL), as shown in Exhibits 2-2 through 2-5. Then we estimated the same values based on data provided by the Tellus Institute, as shown in Exhibits 2-6 through 2-9. Finally, we averaged the two sets of estimates to obtain the values shown in columns "b" and "c." Note that for corrugated cardboard, the process energy GHG emissions are higher when using recycled inputs than when using virgin inputs (as shown by the positive value in column "b" for corrugated cardboard). This is because the manufacture of corrugated cardboard from virgin inputs uses a high proportion of biomass fuels -- whose biogenic CO_2 emissions are not counted as GHG emissions (see the discussion of biogenic CO_2 emissions in Chapter 1). Still, because of forest carbon sequestration, the net

Explanatory notes for Exhibit 4-3 (continued):

GHG emissions from recycling corrugated cardboard are lower than the net GHG emissions from the re-manufacture of corrugated cardboard from virgin inputs. Also note that the transportation GHGs for newsprint from recycled inputs are higher than for newsprint from virgin inputs. This is because Tellus estimated much higher transportation energy for recycled inputs than for virgin inputs (FAL estimated nearly equal transportation energy).

For column "d," which presents the process non-energy GHG emissions from recycling, we used (1) data provided by FAL showing the difference in process non-energy GHG emissions between making one ton of the material from 100% virgin inputs, and from 100% recycled inputs (as shown in the second to last column of Exhibits 2-2 and 2-4) multiplied by (2) the estimated amount of material manufactured (in tons) from one ton of material recovered, after accounting for loss rates in the recovery and remanufacturing steps.

Next, in column "e," the exhibit shows the estimated forest carbon sequestration from recycling of paper products, as estimated in Chapter 3. The last column (column "f") sums columns "b" through "e" to show the GHG implications of recycling each material.

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